ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ
СО АН СССР

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Abstract

The cross-section of the reaction $e^+e^- \to e^+e^-\gamma$ was measured at the electron-positron collider VEPP-2M in the total energy region 0.64-1.40 GeV. The upper limit on the production cross section of the heavy electron was obtained for the mass interval 0.12-1.0 GeV.

The study of the process $e^+e^- \to e^+e^-\gamma$ was aimed at two purposes: a test of QED in α^3 approximation and a search for the heavy electron in the reaction $e^+e^- \to ee^* \to e^+e^-\gamma$. In addition, the study of this process allows its correct subtraction as a background for the reactions of hadron production.

In 1978 at VEPP-2M storage ring with the OLYA detector an experiment was performed aimed at the study of the e^+e^- annihilation into hadrons in the energy region $0.64 \leq \sqrt{S} \leq 1.40$ GeV. The collected integrated luminosity was about 1500 nbn^{-1} /1/. During the analysis of the experimental data the events of the reaction $e^+e^- \to e^+e^-\gamma$ were also selected.

For the reliable identification of the reaction $e^+e^- \to e^+e^-\gamma$ events were chosen with all final particles detected. This allowed to determine particle energies with the help of measured emission angles of the outgoing particles using momentum and energy conservation laws. The method of kinematics reconstruction and the factors which determine the resolution for the particle energies and invariant masses were described in detail for the OLYA detector in the ref. 2. In the energy interval under consideration the angular resolution of the detector was about 1° for the charged particles and about 3° for photons. The resolution for the $e\gamma$ invariant mass was $\simeq 20$ MeV depending only slightly on energy.

The selection $e^+e^- \to e^+e^-\gamma$ events was done in two stages: first the events with two charged particles and photon were selected ($2C + \gamma$), second the events containing electrons were separated ($2e + \gamma$).

The events $2C + \gamma$ were selected by the following criteria.

1. There are two tracks and a single photon detected by the coordinate chambers and the shower-range system respectively.

2. All particles are detected in the different quadrants of the detector that prevents the mixing of the different particle showers.

3. Acollinearity angle for the charged particles $\Delta\omega > 10°$. This is necessary for the reaction plane to be rather well determined.

4. Acoplanarity angle. i.e. the angle between the direction from the interaction point to the point of the photon conversion and the plane containing the charged particle tracks, $\Delta\varphi < 5°$.

5. The energy of each particle obtained by the kinematics reconstruction with the assumption that charged particles are electrons is greater than 150 MeV. This condition diminishes the uncertainty in the detection efficiency of the low energy photons and improves the quality of the electron-meson separation.

The separation of electrons and mesons was performed with the help of scintillation sandwich signals using the correlation matrix method described in ref. 3.

The whole energy region was divided into 12 intervals and each of them was analysed as described above. The region near ϕ - meson resonance was excluded because of the large background from reactions $e^+e^- \to \phi \to K_S K_L, \pi^+\pi^-\pi^0$. The results of the analysis are given in the table. Each line of this table contains energy interval bounds, integrated luminosity, the number of events of $2C + \gamma$ and $2e + \gamma$ types.

The detection efficiency for the reaction $e^+e^- \to e^+e^-\gamma$, theoretical dependence of the total cross-section on energy as well as differential distributions for various parameters were obtained by the detailed Monte-Carlo simulation with the use of the differential cross-section calculated in ref. 4. The simulation took into account all the processes of electron and photon interactions with the material of the detector and the requirements used for the selection of the events.

The total cross section of the reaction $e^+e^- \to e^+e^-\gamma$ as the integral over all acceptable phase-space tends to infinity. To give a physical sence to this value it is necessary to impose some restrictions on the integration region. More definitely the following conditions were chosen: the energy of charged particles had to be greater than some quantity E_{min}, the acollinearity angle greater than some δ, and the emission angles of all final particles - greater than some θ_0 /5/. The specific quantities of the restriction parameters were chosen in such a way that the integration region contained with some extension the phase space volume of final particles available to the detector. They were: $E_{min} = 25$ MeV, $\delta = 5°$, $\theta_0 = 37°$. Figs. 1-3 show the differential distributions of the particle energies and $e\gamma$ invariant mass. The hystograms represent the simulation results, points - the experiment. The errors are statistical. Fig. 4 shows the energy dependence of the total cross section. The solid line corresponds to the QED prediction taking into account radiative corrections due to the emission of real photons by initial and final particles. The contribution of the radiative corrections to the total cross-section is about 8% and negative.

One can see from the figures that the experimentally obtained differential distributions and the total cross section don't contradict to the QED.

The spectrum of the $e\gamma$ invariant mass was used to search for heavy electron (HE), hypothetical particle suggested by Low /6/ in 1965. HE has the same quantum numbers as an electron and differs from the latter by its mass only. The interaction of HE with ordinary electron and photon is characterized by a dimensionless constant λ. For the known experimental limits on λ /7/ the radiative decay width of the HE does not exceed a few keV. Therefore HE has to appear as a narrow peak in the $e\gamma$ invariant mass spectrum. The ref. 8 contains the calculation of the $e^+e^- \to e^+e^-\gamma$ cross section taking the HE into account. The result of this calculation was used for the determination by the Monte-Carlo simulation the HE detection efficiency for the different values of its mass and the beam energy. As the experimental distribution does not contain any peaks an upper limit on the constant λ was obtained. The hystogram bin width $\Delta = 40$ MeV was chosen to be of the same order as the detector resolution for $e\gamma$ invariant mass. In such a case the number of events in the bin i is $N_i = N_i^{QED} + N^{HE}$, where N_i^{QED} and N^{HE} are the contributions of the ordinary bremsstrahlung and the reaction with the heavy electron respectively:

$$N_i^{QED} = \frac{d\sigma^{QED}}{dM} \cdot \Delta \cdot L \cdot \varepsilon_1$$

$$N^{HE} = \lambda^2 \tilde{\sigma} L \varepsilon_2$$

Here M is the HE mass,

$\varepsilon_1, \varepsilon_2$ are the detection efficiencies for each reactions,
L is the integrated luminosity,
$\tilde{\sigma}$ is the total cross-section of the reaction ee → ee* at $\lambda = 1$.

As far as the mass spectrum does not contradict statistically to QED, the evaluation of the upper limit for λ was done as follows:

$$\lambda^2(M_i) < 2.4\sqrt{N_i}\,/\,(\tilde{\sigma} L \varepsilon_2).$$

The confidence level is determined by the numerical factor and equals 95%.

Fig. 5 shows the results of this experiment on the search for HE and the two best previous results of other groups in mass region 100-1000 MeV /7,9/. Recently results of different groups from DESY appeared /10-12/. At PETRA storage ring they studied the QED processes and obtained the limits for the HE in the two photon annihilation reaction. The best result is $M/\lambda > 40$ GeV, that for M = 0.5 GeV is close to our limit $\lambda < 0.015$.

In conclusion the authors express their sincere gratitude to the VEPP-2M staff that ensured the good machine performance during the experiment and to E.A.Kuraev for the useful discussions on theoretical questions.

Table

$\sqrt{S}$ (MeV)	L (nb^{-1})	2C + γ	2e + γ
640-690	27	50	$37\pm^{11}_{14}$
690-750	106	192	$163\pm^{14}_{13}$
750-800	97	355	$223\pm^{33}_{34}$
800-860	136	346	$218\pm^{17}_{17}$
860-920	132	266	$211\pm^{15}_{14}$
920-980	136	344	$280\pm^{17}_{16}$
980-1008	72	176	$131\pm^{12}_{11}$
1120-1180	88	170	$121\pm^{12}_{11}$
1180-1240	120	164	$115\pm^{11}_{10}$
1240-1300	145	206	$163\pm^{13}_{12}$
1300-1360	161	256	$169\pm^{14}_{13}$
1360-1400	126	219	$152\pm^{13}_{13}$
Total	1346	2774	1983

Figure captions

Fig. 1. The distribution on charged particle energies.

Fig. 2. The distribution on the photon energy.

Fig. 3. The $e\gamma$ invariant mass distribution.
(Points-experiment, hystogram - M.C. simulation).

Fig. 4. The total cross section energy dependence
(points-experiment, solid line - QED prediction),

Fig. 5. The upper limit on λ at 95% C.L.
1 - ref. 9
2 - ref. 7
3 - this experiment.

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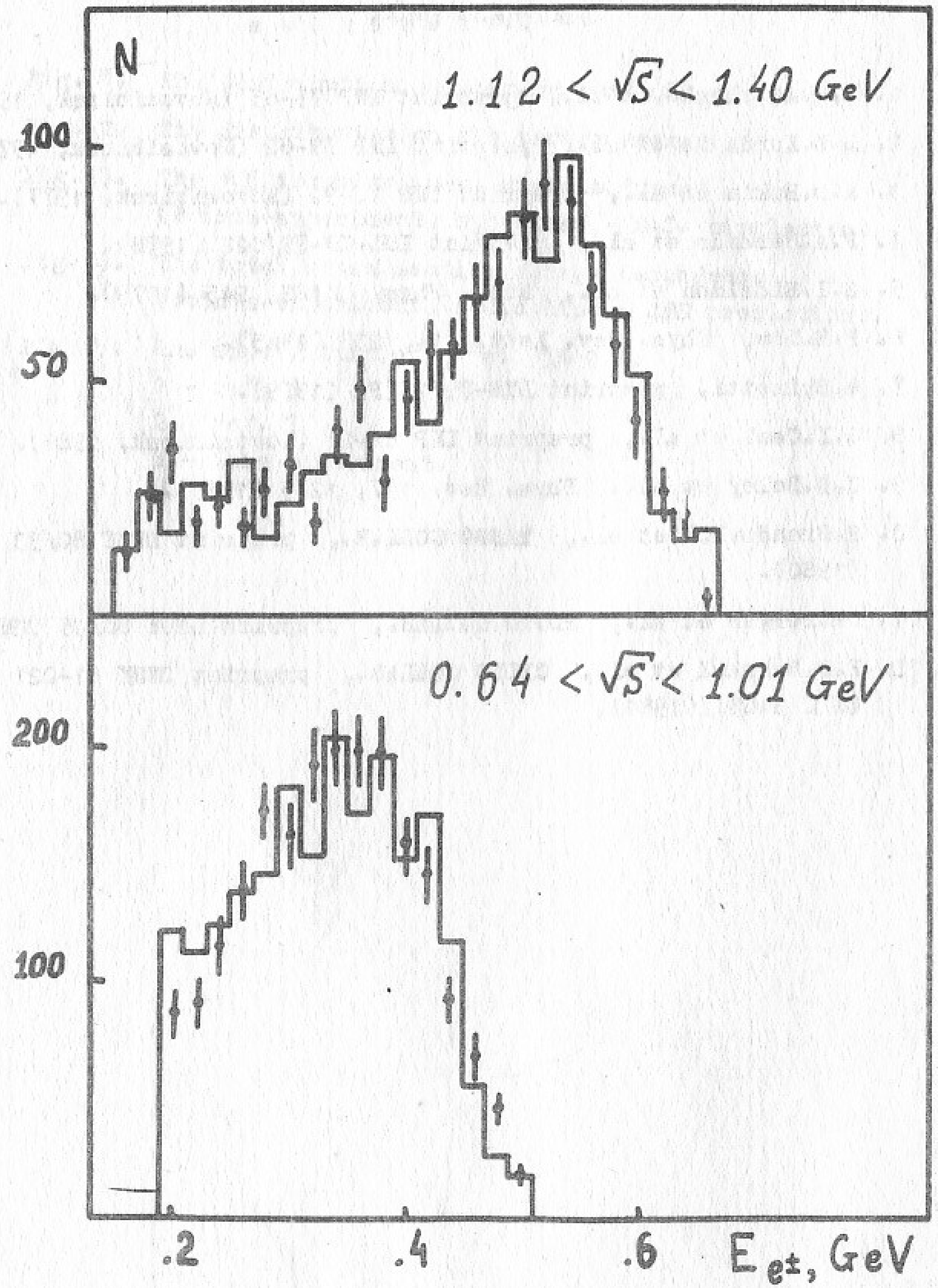
N
1.12 < √s < 1.40 GeV
100
50
0.64 < √s < 1.01 GeV
200
100
.2
.4
.6
E_e±, GeV

Fig. 1.

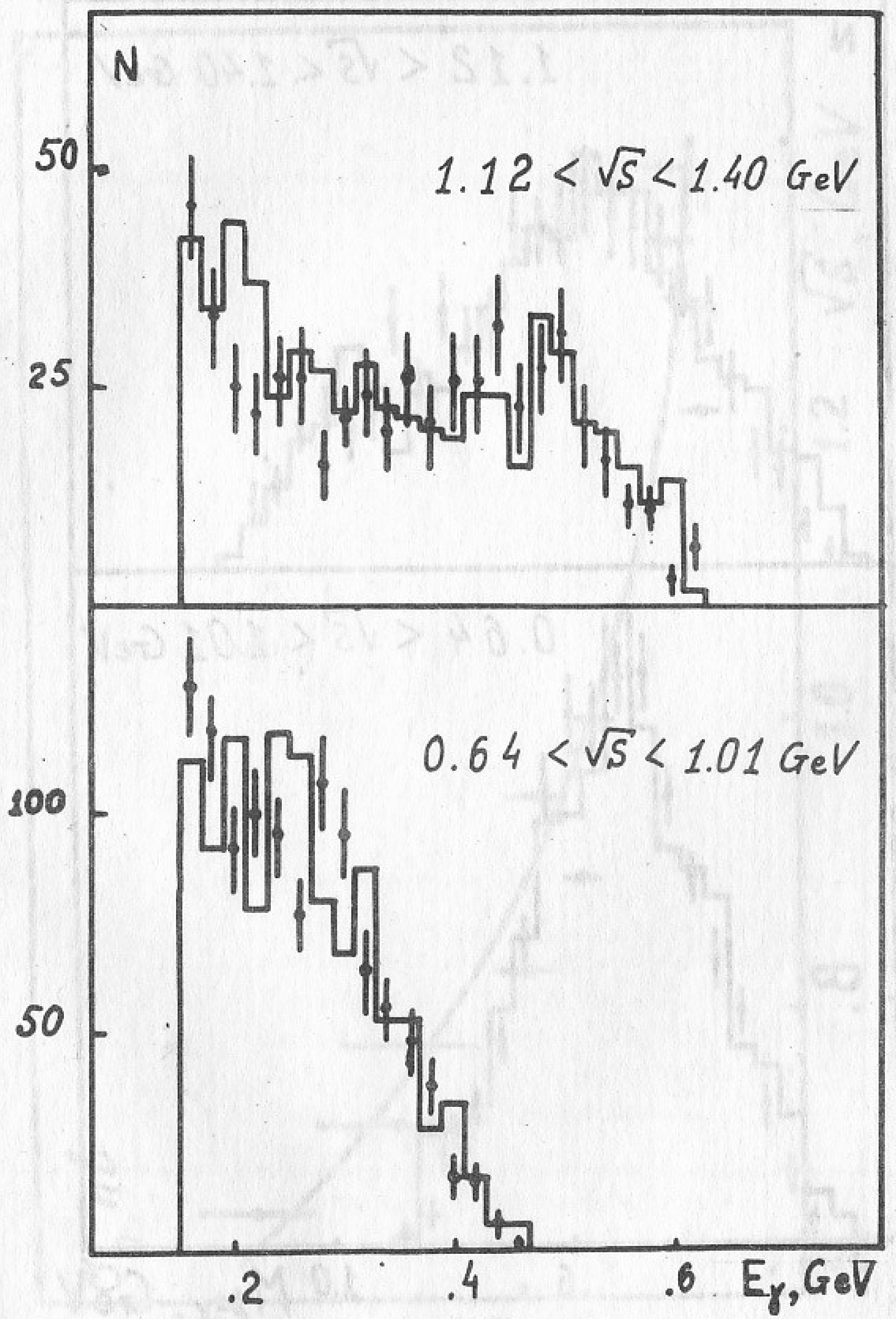
N
50
25
1.12 < √s < 1.40 GeV
100
50
0.64 < √s < 1.01 GeV
.2
.4
.6
E_γ, GeV

Fig. 2.

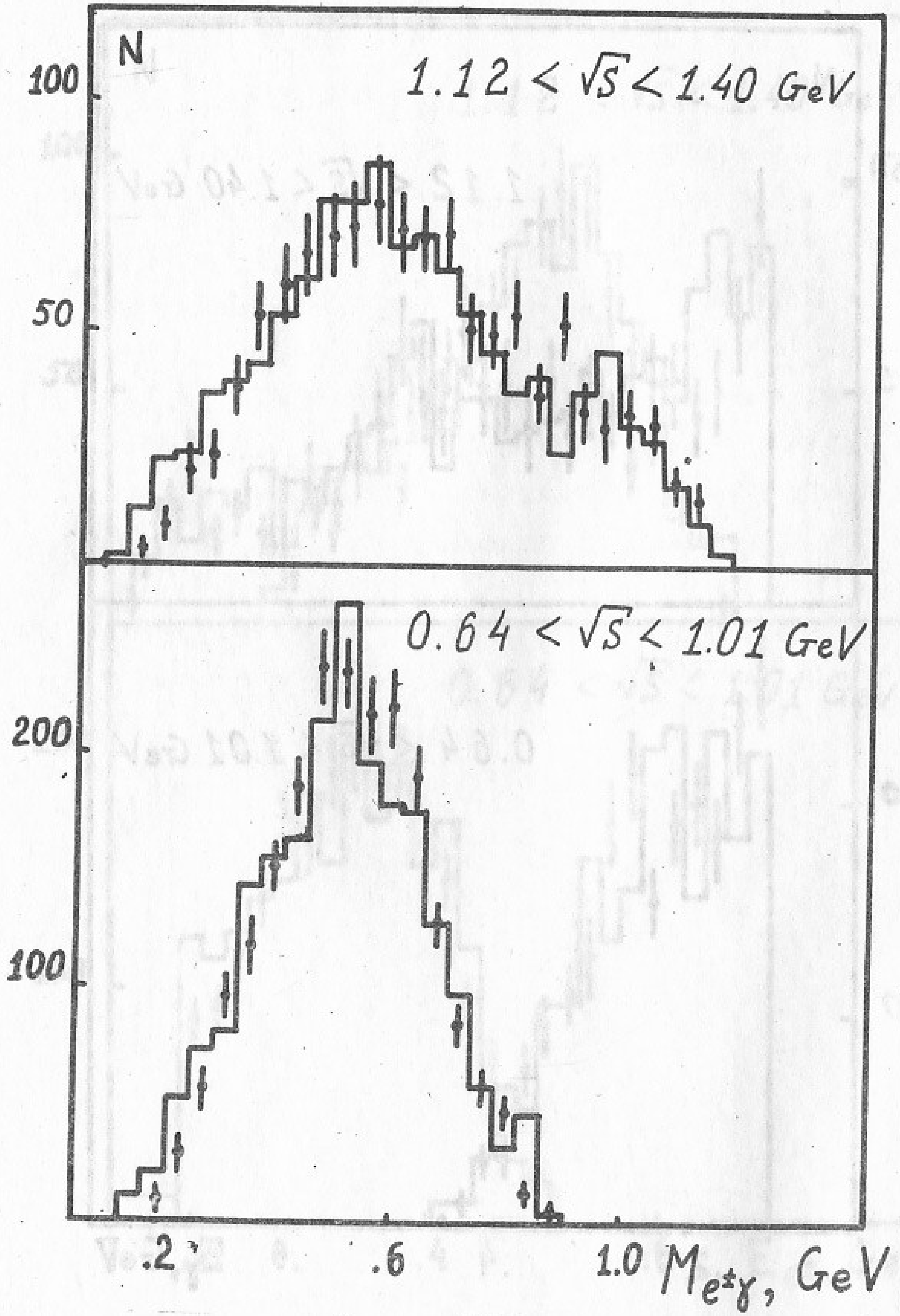
N
100
50
1.12 < √s < 1.40 GeV
0.64 < √s < 1.01 GeV
200
100
.2
.6
1.0
$M_{e^{\pm}\gamma}$, GeV

Fig. 3

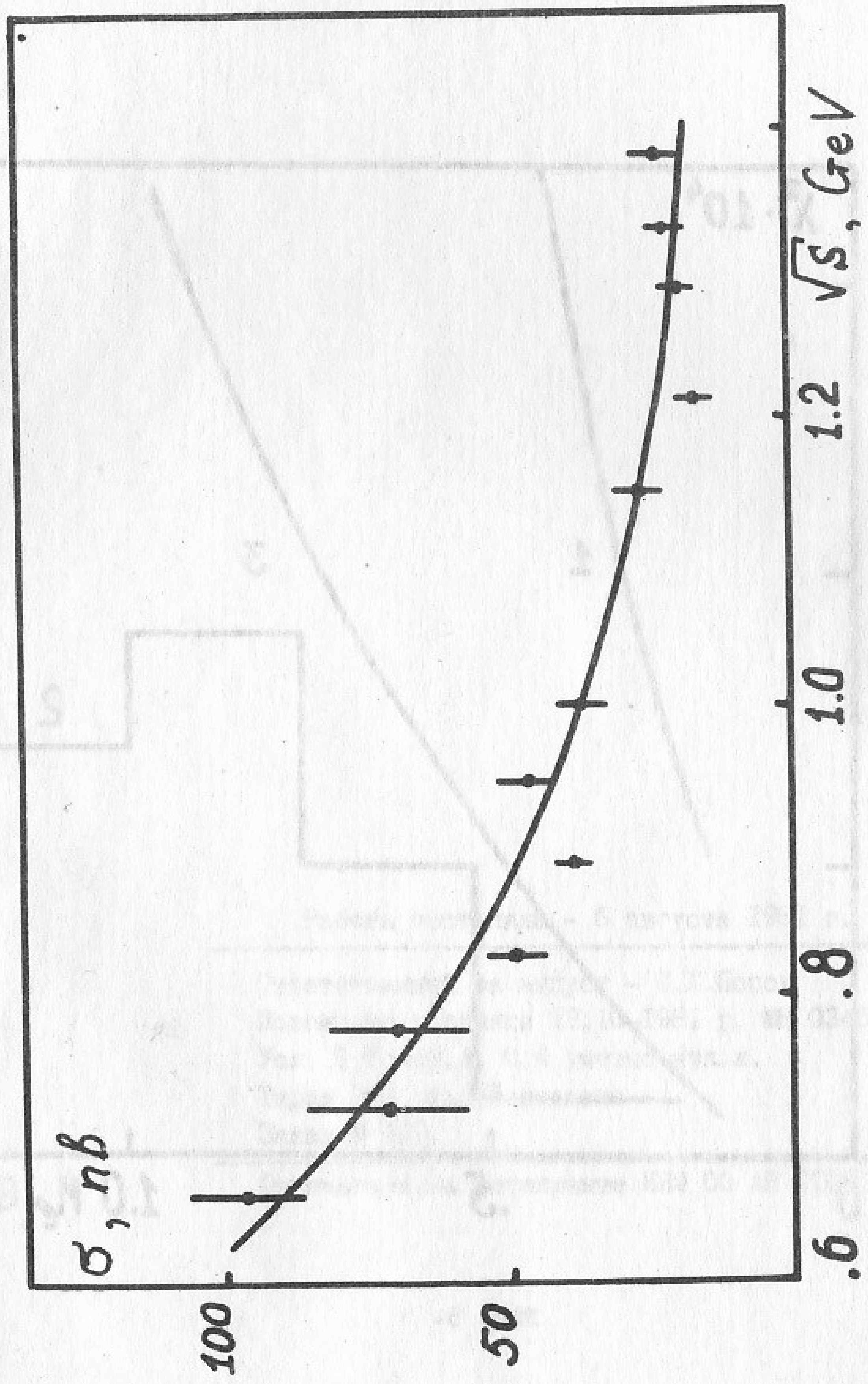
σ, nb
100
50
.6
.8
1.0
1.2
√s, GeV

Fig. 4.

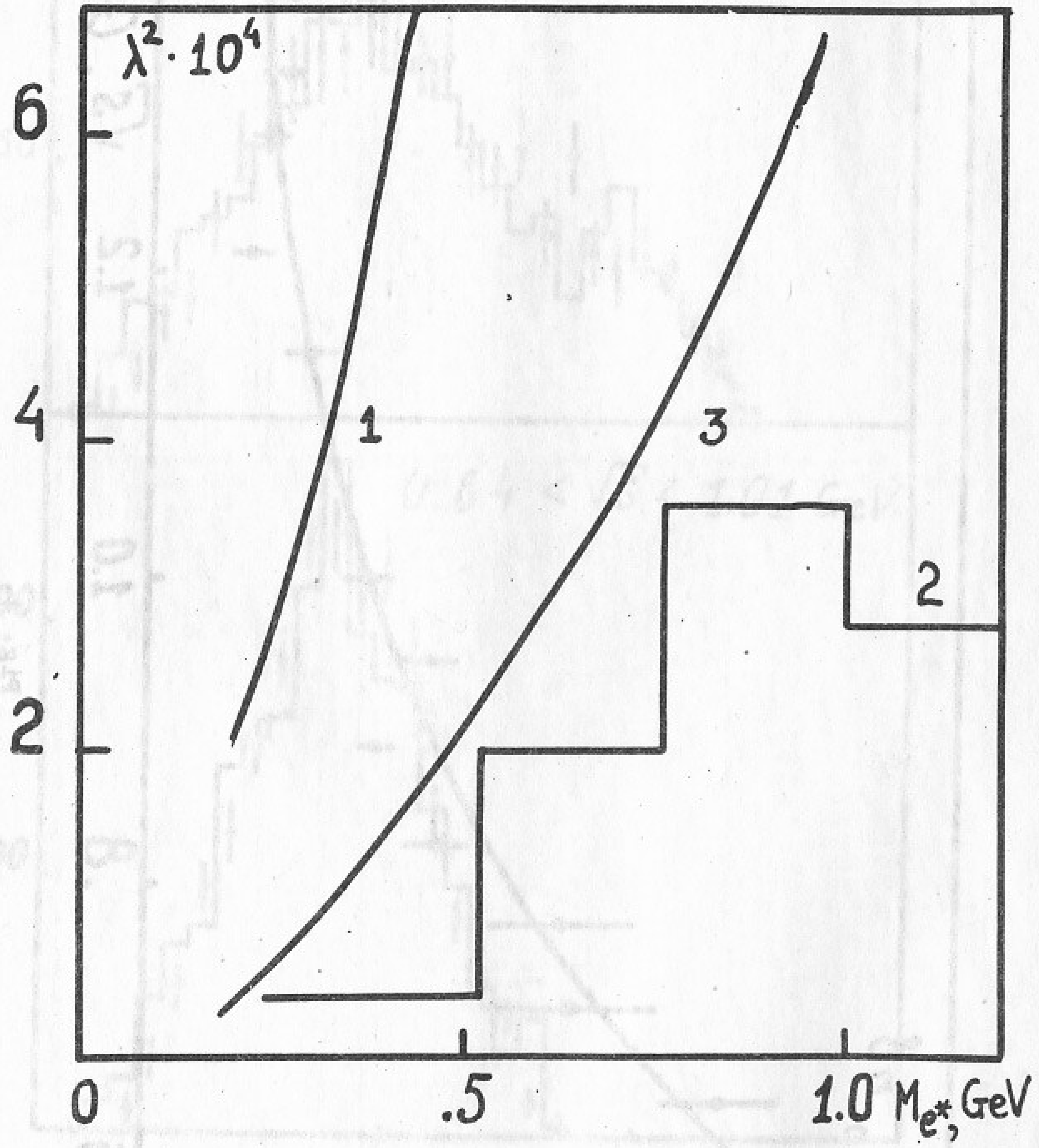

Fig. 5.

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